
Flight Test Research at NASA Ames Research Center: A Test Pilot's Perspective

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Abstract

In 1976 NASA elected to assign responsibility for each of the various flight regimes to individual Research Centers. NASA Ames Research Center at Moffett Field, California was designated lead center for vertical and short takeoff and landing, V/STOL research. This paper will discuss from the test pilot's perspective the three most recent flight research airplanes being flown at the Center: the Quiet Short Haul Research Aircraft, the XV-15 Tilt Rotor Research Aircraft, and the Rotor Systems Research Aircraft.

The Quiet Short Haul Research Aircraft

The Quiet Short Haul Research Aircraft (QSRA), Fig. 1, was designed to further research the concept of upper surface blowing (USB) as a means of developing a quiet short takeoff and landing (STOL) airplane using powered lift. Four high-bypass turbo jet engines are mounted above the wing. For high lift, the flow is turned downward over smooth curved flaps located at the trailing edge of the wing and directly behind each engine. For approach and landing, these flaps are deflected 50°; the resulting downward flow converts part of the engine thrust directly to a lift force. An important feature of the QSRA is to provide propulsive lift at a low noise level. The above-the-wing location of the engines provides a high degree of shielding of the engine exhaust noise, and noise suppression material is installed in the fan inlets, around the core engines, and in the exhaust ducts. The resulting noise footprint is estimated to be 1/7 that of an equivalent jet transport.

The QSRA was designed solely as a low-speed research aircraft. The fuselage, empennage, and landing gear are essentially that of a de Havilland C-8A Buffalo. Numerous structural modifications were made by the Boeing Aircraft Company. The major modification consisted of reinforcing the fuselage and mounting the newly designed wing containing the four engines, the USB flaps, two double slotted flaps, one outboard of each USB flap and drooped/blown ailerons. While the entire focus of the QSRA research was in the low-speed region, the wing itself was representative of a wing capable of an efficient cruise at Mach 0.74. The maximum demonstrated takeoff gross weight is 57,000 lb. The airplane has a relatively high wing loading, 95 lb/ft², a thrust-to-weight ratio of 0.5, and can

sustain a maximum sink rate of 12 ft/sec at the design landing gross weight of 50,000 lb.

When the QSRA was delivered to NASA Ames (August, 1978), it was apparent that the USB propulsive lift generated for the full-flap case was below what had been predicted. In addition, the pilots also commented about an asymmetry in the roll axis and what appeared to be an unsteady flow phenomenon; substantial lateral trim was required and random vertical accelerations were experienced. Past experience with the QSRA model in the 40- by 80-Foot Wind Tunnel at NASA Ames suggested that the problem was the less-than-optimum placement of the vortex generators. Tufting the wing behind the engines was impractical, therefore a careful study of the soot patterns on the upper surface of the wings was done and it provided the primary clues for the proper placement of the vortex generators. It is interesting that the difference in approach speed between having no vortex generators, to having one with a properly designed vortex generator pattern was 15 knots. Another factor found to have a significant effect on the USB lift generated was the character of the flow between the two engines which proved to be critical to good flow-turning performance.

At low altitude with maximum USB flap deflection (66°), maximum thrust, and full aft elevator, the QSRA has a nose-down pitching moment at or near 8° angle of attack. This anomaly was attributed to an elevator-stall phenomenon. The pitching moment exceeds the capability of the available elevator causing the nose-down attitude change. Recovery is achieved by either reducing thrust, USB flap deflection, or increasing airspeed. Resetting the elevator incidence angle 3° more negative provided some increase in the maximum pitch control available but did not totally eliminate the elevator-stall phenomenon.

Almost all pilots who check out in the QSRA at one time or another experience a "wheel barrowing" tendency during a touch-and-go landing. Once on the ground, if power is added before the USB flaps are retracted, the lift generated is sufficient to raise the main gear off the runway while the nose gear remains thereon. During the performance testing, it was shown that at a normal approach speed of 65 knots, the QSRA could barely maintain level flight with 50° USB flap and full thrust; however, at 30° of USB flap, a climb angle of nearly +6° could be maintained. The standard go-around procedure became one of retracting the USB flaps to 30° and then advancing the throttles to maximum thrust. Climb performance was greatly increased and the "wheel barrowing" tendency considerably reduced.

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Flight testing any powered lift airplane is complicated by the fact that lift performance is heavily dependent on engine thrust (which varies with altitude), temperature, and thrust coefficient (which varies with velocity). It is always necessary to collect and process large quantities of data to construct meaningful performance plots. Figure 2 (from item 3 in Bibliography) shows flight path versus velocity for the QSRA in the landing configuration at 48,000 lb with the USB flaps at 50°. A normal approach is at 65 knots with a flight-path angle of -6 to -7.5°. For a fan speed of 70% rpm (approximately one half the thrust available), the pitch attitude is just above a level attitude (between +3° and +4°) with an angle of attack near 10°. Note that lines of constant pitch attitude are nearly vertical at this point and that lines of constant angle of attack have a significant slope. This illustrates the need to fly the QSRA--and in general most powered lift airplanes--at constant pitch attitude rather than constant angle of attack as is more common for conventional airplanes.

Pilot experience indicated that any distraction during the approach could result in significant deviations from the desired approach speed. An automatic speed-stabilization system was developed that "slaved" the USB flaps to a digital airspeed system. The system had an authority of $\pm 10^\circ$ whenever the USB flaps were extended beyond 30°. The system worked well and reduced pilot workload during the approach, but some problems were experienced in ground effect.

Another piloting problem was discovered during engine-out approaches. There was strong tendency toward a lateral (roll) pilot-induced oscillation. It was determined that the roll trim point was very close to the point where spoiler activation (30° wheel deflection) occurred. The ultimate solution was to program the spoilers to operate as a continuous and linear input along with the ailerons. This modification greatly improved the precision of the roll control for engine-out approaches. Further, the ability to deploy the double slotted flaps asymmetrically allowed the pilot to almost completely trim the engine-out rolling moment and fly with a nearly neutral wheel position.

In the spring of 1979, a joint NAVY/NASA flight program was undertaken to investigate the application of propulsive lift technology to the aircraft-carrier environment.

The primary objectives of the program were to determine the best techniques for operating STOL aircraft aboard aircraft carriers and to obtain design data for development of operational criteria for future Navy use. Of particular interest was to develop the best STOL landing technique; determine the effects of ship's wake, ground effect and motion on the approach; and general shipboard operation and handling of the airplane.

Normally, a conventional aircraft flies a carrier approach at constant angle of attack. As indicated previously, attempts at flying constant angle of attack approaches in the QSRA resulted in excessive airspeed excursions and only marginal flight-path control. Previous experience had also shown that flying a flat approach angle resulted in a tendency to float because of a strongly positive ground effect. It was decided to fly the carrier approach as steeply as possible without exceeding the QSRA's landing gear limit sink rate of 12 ft/sec. A 4.5° aerodynamic flight-path angle, flown at 65-70 knots, with a pitch attitude between +1° and +3° allowed the airplane to fly a comfortable approach, cross the ramp with adequate safety margin and touch down without a flare, with a nominal sink rate of just under 9 ft/sec.

The basic longitudinal rate command stability augmentation system (SAS) was required for all approaches. The more important control requirement, however, was for direct lift control (DLC) provided by the highly effective spoilers on the wings. Spoilers were deployed to a nominal setting and operated both up and down from that position. The increased drag was offset by a higher power setting which, incidentally, placed the engines in a more responsive power range. Without DLC, flight-path control was severely degraded and occasionally resulted in a longitudinal pilot-induced oscillation near touchdown. It was a relatively easy piloting task to fly the desired glide path until about 100 ft, at which point the QSRA encountered the ship's aerodynamic wake or "burbles." The initial tendency was to go slightly high followed by a somewhat abrupt settling as the airplane crossed the carrier's round down. After a few approaches, it was possible to anticipate the settling and increase power at the appropriate time to continue on the glide slope. The Navy was especially impressed with the wave-off capability of the QSRA. The more difficult task was runway alignment. Since the steep approach angles exceeded the capability of the ship's standard Fresnel lens, it was necessary to use a portable Fresnel lens on the ship. This lens was located 250 ft aft of the normal lens and farther to the left of the carrier centerline than it had been during the field carrier landing practice. The result was a tendency to land to the left of the prescribed centerline.

Takeoffs were performed from both the axial and angle decks. The USB flaps were set at 10° and the double slotted flaps at 59°. Power was set at 80% fan speed prior to brake release and maximum power applied immediately after brake release. Full aft column was applied after the first indication of airspeed. The airplane rotated comfortably at 60 knots and lifted off at 70 knots. Takeoffs were smooth and precise.

In a four-day period of sea trials, 25 low approaches, 37 touch-and-go landings, and 16 full-stop landings were made on the USS Kitty Hawk (CV-63), Fig. 3. It was concluded that USB

propulsive lift technology presented no unusual problems in the aircraft-carrier environment.

It is commonly believed that high-performance propulsive lift airplanes are difficult to fly. The QSRA is certainly an exception to this rule. In general, it has a very natural feel and pilots readily adapt to its characteristics. Twenty-five "guest" pilots with a wide variety of experience and backgrounds were invited to fly the QSRA. By the third flight, each pilot was able to fly a steep STOL approach with one engine inoperative and the SAS turned off. No unusual piloting skills are required.

The research capability of the QSRA is currently being used to investigate advanced electronic display and advanced augmentation systems for a powered-lift airplane under instrument conditions in the terminal area.

The XV-15 Tilt Rotor

A fixed-wing airplane is limited in its low speed by the stall. On the other hand, a helicopter is limited in its high speed by the retreating blade stall. The XV-15 tilt-rotor research airplane, Fig. 4, is an attempt to combine the qualities of a fixed-wing airplane and a helicopter to achieve a high-speed vertical takeoff and landing (VTOL) airplane with the hover efficiency of a helicopter. The XV-15 tilt-rotor research airplane was built by Bell Helicopter Textron under contract to NASA and the U.S. Army.

In the helicopter mode, lift is provided by two three-bladed, 25-ft diameter proprotors attached to wing tip mounted engine nacelles rotated to the near vertical position. In this mode, the aircraft flies like a twin-rotor helicopter and is controlled by cyclic and collective control inputs to the proprotor. The collective provides simultaneous input to all six blades for vertical control; lateral stick produces roll control through differential collective pitch changes to each proprotor; longitudinal cyclic inputs command cyclic pitch changes simultaneously to both proprotors for fore and aft translation; and the rudder pedals command differential cyclic pitch inputs to provide yaw control. During helicopter operation, all of the fixed-wing control surfaces (conventional ailerons, rudders, and elevators) are operable; however, they are simply ineffective at low speeds. The pilot initiates conversion by pressing a spring loaded "coolie-hat" switch located on the collective or power lever. All intermediate nacelle angles are available to 95° for the helicopter mode and to 0° for the airplane mode. During conversion from helicopter to airplane mode, the helicopter controls are mechanically phased out as the nacelles rotate forward. As the speed increases, the conventional airplane controls become effective. It is, of course, possible to fly at intermediate nacelle angles or to reconvert as desired. The proprotors are driven by

two modified T-53 engines located in the wing tip nacelles. Either engine is capable of driving both proprotors through a cross shaft located in the wing which allows for an engine failure and still retains power to both proprotors. Single engine capability in the intermediate nacelle angle mode has been demonstrated by simulated failures and two actual engine failures.

The tilt-rotor concept is not a new one. The XV-3 (Fig. 5) was flown in the 1950s and has demonstrated the feasibility of converting from a helicopter to an airplane. While there were several technical reasons that prevented further development at that time, the real "show stopper" was a low-frequency rotor-pylon instability that was discovered during intensive wind tunnel testing. Advances in engine performance, structures, and stability and control led to the development of the XV-15. The XV-15 first flew in the spring of 1977 and has been in continuous flight test since that time.

The first thing a pilot notices when being introduced to the XV-15 is that on the ground the airplane is sensitive to lateral control inputs, and during ground taxi there is a tendency for the airplane to lean into turns, thereby requiring a small amount of lateral control to keep the wings level. Movement of the nacelles provides a responsive and natural means of accelerating and decelerating during taxi, practically eliminating any requirement for longitudinal cyclic inputs. A nacelle tilt of only 2-3° results in a comfortable 10-knot ground speed with neutral cyclic. With a little differential braking the XV-15 is easily turned within its own radius.

Hovering the XV-15 out of ground effect is considered quite easy, similar to most tandem rotor helicopters. Only small cyclic inputs are required to maintain a precise hover over a preselected spot. The only complaint ever voiced is the requirement for small yaw inputs to keep the airplane lined up directionally. In ground effect, hover is equally good until the airplane reaches 2 to 3 ft above the ground. Pilot workload is increased considerably, particularly in the roll axis. There is also a small but noticeable "suck-down" when landing vertically, but it is easily controlled. If space is available, it helps to be moving slightly forward at low speed for the final touchdown. As in all helicopters, the question arises as to what happens if you lose an engine in hover and do not have single engine hover capability. To cope with an engine failure in the XV-15, it has been concluded that a high hover is desirable to allow the pilot to tilt the nacelles forward 5° to 10° to accelerate for a run-on landing.

A wide hover envelope has been demonstrated which includes sideward and rearward flight to 25 knots. In sideward flight, there is a noticeable increase in vibration. In rearward flight, there is an observable nose-down pitching moment caused by airflow over the horizontal tail. The

preferred method of translating rearward is to use the full aft nacelle setting of 95° and rotate the nacelles forward to stop. In general, there is really nothing unusual about the XV-15 in the helicopter mode. It is a highly stable hover platform allowing precision hover with low pilot workload. As with conventional tandem rotor helicopters, it is affected very little by wind direction.

From a piloting viewpoint, the most interesting feature is the conversion. As indicated previously, nacelle tilt is controlled by a "coolie hat" located on the collective control. The pilot can "beep" the controller or hold it down for a continuous conversion. Nacelle tilt rate is 7.5°/sec, slowing to 1.5°/sec within 5° of either end of the tilt mode. The XV-15 conversion corridor is quite wide, meaning the pilot does not have much concern over whether he will exceed some particular velocity for a given nacelle setting. The conversion is quite natural and there is very little longitudinal trim change and low pilot workload. Of course, the conversion process can be stopped at any intermediate setting or a reconversion accomplished from any nacelle tilt angle. The longitudinal acceleration associated with changing tilt angle is quite noticeable and occasionally it is noted as being mildly abrupt, depending on the pilot's technique during "beeping" of the tilt controller.

The limits on the conversion corridor are structural and are not due to handling qualities. The established conversion procedure is to accelerate to between 60 and 80 knots with the nacelles at the 70° to 80° position while retracting the landing gear. At airspeeds past 90 knots the nacelles are usually "beeped" continuously. The flaps are raised from 40° to 20° at 60° nacelle tilt angle and fully retracted by 150 knots. There is a definite increase in cockpit noise as the nacelle tilt passes 30° and the propotor reaches its closest point to the cockpit. Since the pylon tilt rate is automatically reduced to 1.5°/sec within 5° of the stops, a continuous conversion can be accomplished right down to the stops. As the nacelles approach 0° (airplane mode) there is a pronounced nose-down pitching moment which must be corrected with a little aft cyclic. There is little change in roll sensitivity or of the handling qualities in general as tilt angle is varied. The conversion is best described as a straightforward process which has been comfortable for all pilots who have flown the XV-15.

Once the nacelles reach 0°, they are "locked" down using a small toggle switch located just forward of the conversion switch on the pilot's collective control. This hydraulically forces the nacelles against the downstops. Propotor rpm is then reduced to 86% to preserve the propotor efficiency at the high forward speeds. Although a greater propotor efficiency exists around 76%, the higher rpm reduces the vibratory loads on the conversion spindle and engine coupling gearboxes. At the 0° nacelle tilt angle and reduced rpm, the

frequency and intensity of the sound in the cockpit is considerably reduced. Outside noise is also reduced.

In the airplane mode, the collective or power lever only controls engine power. It is possible to differentially trim the propotor collective pitch angles to reduce any steady state sideslip that may be developed from a power asymmetry. Most pilots feel the roll sensitivity is too low and this makes the XV-15 feel too heavy. The airplane mode also exhibits a turbulence response that is unusual. A vertical gust is felt as a longitudinal "chugging" which is caused by the transient changes in blade angle of attack and can result in noticeable thrust changes. In moderate turbulence, this fore and aft motion is best described as uncomfortable.

In the airplane mode, the XV-15 exhibits very docile and conventional stall characteristics. In the clean airplane configuration, stall speed varies between 95 and 110 knots and is usually preceded by a mild buffett or shudder about 5 knots prior to stall. Standard airplane recovery techniques are quite effective. Because of the high drag of the propotors, the XV-15 is capable of quite high sink rates with the power set at idle.

The reconversion process is simple. Below 150 knots the flaps are placed to 20° and propotor rpm is "beeped" up to 98%. A power reduction results in a positive deceleration. The nacelles are unlocked and can be moved continuously upward when the airspeed is reduced below 150 knots. Flaps are lowered to 40° at 60° nacelle tilt. The airplane decelerates rapidly and a forward cyclic input is required to stop a nose-up pitching moment.

While no autorotative landings have been accomplished, steady state autorotations have been entered from 60° to 90° tilt angles. With a stabilized rpm of 92%, sink rates of 3,200 ft/min were found to exist at 80 knots.

Both STOL takeoffs and landings have been demonstrated. Considerable increase in performance is achieved for a very short rolling distance. Both are easily performed and make the pilot look good.

Because of the problems encountered with rotor-pylon-wing instability in the XV-3 "Convertible," investigations of this problem have continued in the XV-15. Destabilizing parameters include swashplate/pylon coupling, wing mode effects, increasing airspeed and propotor rpm. The data from the XV-15 tests are being used to avoid similar problems in the V-22 Osprey.

Extensive hover tests have been conducted to determine wing download and hover efficiency. It was dramatic to experience the effect of wing configuration (flap deflection) on hover performance. The results were predictable and obvious, as you reduce the wing area exposed to the

proprotor downwash, you reduce the power required to hover. With the flaps full up, it required maximum continuous power to hover at 15,000 lb gross weight. As the flaps were extended to 75°, the same power setting resulted in climb rates as high as 1200 ft/min.

Again, in support of the V-22 Osprey, the XV-15 was used to evaluate the use of a three-axis sidestick controller in a tilt-rotor aircraft. Several pilots flew the XV-15 through all modes of flight and unanimously judged the system to be suitable. They found it easier to establish and hold stabilized airspeed points in level flight, and altitude and speed during maneuvers. Part of this was due to the trim follow-up incorporated in design. None of the pilots liked the yaw axis on the sidestick.

The XV-15 was used by the military services to determine the potential of the tilt-rotor concept for various operational missions. These tests included: detectability and survivability against air defense threat systems; contour and nap-of-the-Earth flight; Navy shipboard evaluation; search and rescue; external load capability; simulated aerial refueling from a KC-130 tanker; forward-weapons delivery patterns, and wake-turbulence evaluations.

All operational tests had positive results. It was concluded that the tilt-rotor could operate safely in the terrain flight environment and that its survivability was improved over that of conventional airplanes and helicopters. The tilt rotor operated well in the shipboard environment and integrated easily into the helicopter regime. It was shown that personnel could easily operate beneath the tilt rotor and the downwash presented no unusual problems for external loads or for hoisting survivors. The full potential of the tilt-rotor concept has yet to be explored; it will require new employment tactics and will introduce totally new missions for military use.

The XV-15 has been fitted with new composite proprotors made of high-strain graphite. The blades can be fitted with three different blade tips and three blade cuffs. All phases of helicopter and conversion flight will be investigated.

Overall the XV-15 has proven to be an outstanding research vehicle resulting in major improvements in the field of vertical and short takeoff aircraft.

Rotor Systems Research Aircraft

The Rotor Systems Research Aircraft (RSRA) is a unique research airplane designed to flight test advanced helicopter rotor systems. Its principal flight test configuration is as a compound helicopter, Fig. 6 (combination fixed- and rotary-wing aircraft). The RSRA has been flown as a helicopter, Fig. 7, and also as a fixed-wing airplane, Fig. 8.

The RSRA was designed to allow the existing rotor to be removed and new advanced rotors of different numbers and lengths of blades to be installed. The RSRA has a full set of rotary-wing and conventional aircraft controls, both of which can be operated either mechanically or through a fly-by-wire system. Provisions are made in both control systems to allow them to accommodate different rotor configurations.

Because of the increased number of control surfaces available in the compound configuration, a means of "control sharing" is incorporated in the flight-control system. This is accomplished through a control phasing unit, or CPU, centrally located on the console between the two pilots. The CPU allows the pilot to select the proportion of his control inputs that will be made by the fixed- or rotary-wing control surfaces. This means the pilot can select full rotary-wing or full fixed-wing control, or any combination of the two.

The tail section of the RSRA contains a lower horizontal all-flying stabilator, an upper fixed horizontal tail plane, two large aft-mounted drag brakes, a conventional rudder, and a helicopter tail rotor.

The rotor transmission gear train and tail rotor are driven by two General Electric T-58 engines. Even though the main rotor was removed for the fixed-wing flight tests, it was necessary to operate both T-58 engines to drive the electric generators, hydraulic pumps, and tail rotor. The power plants which allow the RSRA to be flown as a fixed-wing airplane are two General Electric TF-34 high-bypass turbojet engines mounted on either side of the fuselage. In the compound helicopter mode, these engines are derated to 6,250 lb thrust each. For the fixed-wing flight test program, thrust was increased to 8,250 lb. The throttles for the two TF-34 engines are two twist grips located on the collective controller.

The RSRA has a 45-ft wing which is unique because it can vary its angle of incidence from 9° leading edge down to 15° leading edge up. Wing incidence changes are made through two large hydraulic pistons attached to the leading edge of the wing. Control of wing incidence is provided through a handle on the center console between the two pilots. The forces and moments generated by the main and tail rotors, auxiliary engines, and the wing are measured by a series of load cells and/or the active isolation and balance system which is an integral part of the aircraft structure.

The RSRA incorporates a unique blade-severance and crew-escape system. This pyrotechnically operated system allows the crew to independently sever the rotor blades and/or eject from the aircraft. Two Martin Baker ejection seats are installed to provide the pilots with this capability.

Since the compound configuration is too heavy to hover (minimum speed 40 knots), the RSRA can

also be flown as a pure helicopter. This configuration fills the low-speed performance gap and allows complete investigation of a candidate rotor system in the hover and low-speed range. The basic airframe was first flown as a helicopter to check out those systems common to all three configurations prior to adding the airplane parts.

The helicopter configuration is relatively easy to fly and handles very much like a Sikorsky H-3 series helicopter. The original SAS gains were overly sensitive and resulted in a lateral pilot-induced oscillation on landing. Reducing the SAS gains greatly improved the handling qualities. The extreme length of the helicopter requires caution during rapid flare or quick stop maneuvers near the ground.

During the buildup to the compound configuration, the helicopter was flown with the horizontal tail attached and then with the TF-34 engines mounted on the fuselage but without the wing. It was not possible to autorotate in the helicopter mode with the compound configuration horizontal tail installed. The pilot found that he approached the left rudder pedal limit with only a 100 ft/min rate of descent.

The first unique research program took advantage of the rotor-system force measurement system. Highly accurate vertical drag data were obtained in hover and at low speed allowing determination of rotor downwash and fuselage interference effects, thus achieving measurements never before possible in actual flight.

The helicopter configuration was used extensively during the buildup to flying the compound configuration. It was possible to make running takeoffs and run-on landings with the helicopter, matching the compound speeds.

The takeoff technique for the compound is a compromise between that used for a tail dragger fixed-wing aircraft and a rolling takeoff for a heavyweight helicopter. The following technique was established: Establish the cyclic in the near center position using the cockpit control position indicators keeping the collective full down until the takeoff roll begins. Slowly advance the TF-34 engines to takeoff power as the aircraft rolls forward. As takeoff power is stabilized, collective is increased slowly to arrive at 40% collective position and 70 knots simultaneously.

With the wing set at a 10° incidence, the aircraft simply flies off the runway in the 3-point attitude with only minimum control input required to maintain that attitude. Acceleration to 90 knots occurs quite rapidly, and without changing power. A slight aft cyclic movement results in a 90-knot climb. Up-and-away flight is very comfortable, much more so than with the pure helicopter. The compound is more stable and exhibits less vibration.

Movement of the variable incidence wing in flight proved to be rather benign. Essentially, the fuselage rotates about the wing and the angle of attack remains constant. The wing-to-elevator interconnect practically negates the requirement for a cyclic trim change.

The only noticeable effect on the handling qualities with a change in wing incidence is a new flight attitude and quite different power requirements for the auxiliary engines during turning flight. The higher wing-incidence angles require considerably more power in a turn to maintain a constant speed.

The greatest influence of wing incidence is where the maximum stresses occur during high-speed flight. Much of the flight-test effort has been devoted to mapping the structural loads as a function of wing incidence and collective setting. The limiting structural loads at high speed occur either in the main rotor blades or in the upper horizontal stabilizer. At high wing-incidence angle, the horizontal stabilizer reaches its endurance level around 180 knots. At low wing-incidence angle, the main rotor blades reach their endurance levels at about the same speed. A lowering of the collective tends to reduce the rotor loads. A push rod load indicator in the cockpit provides excellent information to the pilot when the rotor loads start to exceed their limits. To date, the structural loads on the aircraft have been mapped at wing angles of 0°, 5°, 7.5°, and 10° from 50 to 180 knots at several collective settings.

The compound configuration is landed very much like a fixed-wing airplane. Approach speeds of 110 knots downwind, 100 knots on base leg, and 90 knots on final, provide an adequate margin above wing stall. Maintaining a constant 20% collective setting and these speeds allows the compound to touchdown in a slight tail-low attitude at 70 knots with only a slight flare.

A 7.5° wing incidence places the aircraft in a 3-point attitude with jets at idle and 70-knot touchdown target. There is no tendency to float or enter any kind of pilot-induced oscillation (PIO) in ground effect. If, in rare occasions, one misjudges the location of the wheels and ends up slightly high prior to touchdown, a slight downward pressure on the collective provides the flexibility to recover gracefully.

The fixed-wing configuration of the RSRA was primarily considered an emergency fly-home mode in the event it became necessary to sever an unstable rotor system in flight. While it had always been planned to flight test the fixed-wing configuration, the selection of the RSRA as the flight test bed for the X-wing rotor accelerated these tests. The X-wing rotor will be the first completely "new" rotor system to be flight tested on the RSRA.

The compound configuration was used extensively in the build-up to the fixed-wing flight

tests. It was used to investigate the lift and stall characteristics of the wing. Near zero lift was obtained on the RSRA rotor and the fixed-wing angle of attack increased to stall. As the wing stalled, lift was rapidly transferred from the wing to the autorotating rotor. A rapid increase in rotor rpm became the best way to determine when the wing stalled. The wing, fuselage, and empennage area were extensively tufted. Photo coverage showed that the stall progressed in a classic manner for a straight-winged aircraft. The root of the wing stalled first, although there was little or no noticeable stall warning that could be felt in the cockpit. Increasing the collective setting to the rotor was a rapid and positive way to decrease the angle of attack on the wing.

The compound configuration was also used to evaluate the transfer of pilot control inputs from a combination rotary- and fixed-wing input to fixed-wing only inputs. Pilot control inputs were incrementally washed out to the rotary wing by advancing the control phasing unit lever to the full fixed-wing position. The airplane was sluggish in this configuration but quite controllable.

The fixed-wing RSRA embodies all the characteristics not to build into a tail dragger airplane if one wanted to reduce its tip-over and ground looping tendencies. The high center of gravity, high-thrust line, high side-force area, and narrow gear, when coupled with low-frequency directional control, caused considerable concern regarding the ground handling of the airplane. The primary reason for keeping the tail rotor on the airplane was to assist in ground handling and to reduce the engine-out speed of this multiengine airplane. The high-speed taxi tests indicated that, while not particularly good, the ground handling qualities were acceptable. It was decided, however, to limit the airplane to crosswinds of less than 15 knots at the lower weight and lower center of gravity configuration, and to 10 knots at the higher weight and higher center of gravity.

The taxi tests confirmed the 5° wing incidence and 15° flap setting for the lighter weight configuration. Because of the rapid acceleration of the airplane, TF-34 power settings had been limited to 70% fan speed or less during the ground taxi tests. At the lighter weight, the thrust-to-weight ratio is approximately 0.7. The tail wheel came off the ground between 75 and 85 knots.

A maximum TF-34 fan speed of 80% was established for the first flight takeoff. On takeoff roll, the copilot calls out fan speed as the pilot manipulates the two throttles while the airplane accelerates down the runway. Difficulty in matching engine power compounds the directional control problem.

At liftoff there is a slight tendency to over-control the airplane in pitch. Climb performance is impressive with climb speed at 150 knots. Up-and-away, the fixed-wing airplane is quite stable, very similar to a medium-weight

transport. Control sensitivity at 150 knots is low and the damping high in all axes. Control sensitivity increases rapidly with speed, becoming quite sensitive above 180 knots.

The tail rotor is the limiting factor on the maximum speed that could be attained. It is necessary to keep the tail rotor tip speed below Mach 1; this is accomplished by reducing tail rotor rpm to 94% and limiting the maximum speed of the aircraft to 250 knots. To further reduce structural loads on the tail rotor, above 200 knots, rudder pedal inputs are prevented from reaching the tail rotor by moving the yaw control phasing unit to the full fixed-wing position and restricting sideslip to less than 7.5°.

Most of the up-and-away flying was devoted to the primary task of determining the control power available for each control axis. Performance data were obtained during the envelope expansion flights. An anomaly noted during the stability tests was that the airplane exhibited a different response for nose-up and nose-down inputs. Nose-down inputs tended to appear uncoupled from the roll axis while nose-up inputs always resulted in a roll to the left. It is believed that this is caused by air flow interaction with the tail rotor.

For the landing approach, the airplane flies nicely at a 140-knot approach speed and is easily controlled down to 120 knots. The planned touchdown speed is near 115 knots. The airplane could be landed in the 3-point wheel landing or tail-wheel first attitude. The determining factor is how slow you get in the landing flare. The actual landing is less of a problem than the considerable attention required for directional control once on the ground. The shutdown of the right TF-34, required to reduce landing distance, aggravates the directional control problem. Total landing distances as low as 5,500 ft were demonstrated. Stopping distances of 2,500-3,000 ft are required.

During the fixed-wing flight tests, two different rotor hubs were flown, providing a unique flight-test opportunity. With the variable incidence wing, aircraft pitch attitude could be changed while maintaining the same airspeed and altitude. This allowed a complete set of pure rotor-hub-drag data to be obtained by comparing the drag of the RSRA with and without the main rotor installed.

The fixed-wing flight test program provided invaluable data for the design and flight-test efforts of the RSRA/X-wing aircraft. The X-wing is an inflight stoppable and restartable rotor that uses circulation control for both lift and control. The capability of the RSRA to provide independent control of both lift and drag, together with its unique flight-control system, make it the ideal test vehicle to research and demonstrate X-wing technology in flight. Flight test of the X-wing rotor should commence in the Fall of 1987.

The RSRA provides the flight test community a versatile research tool. It will play an important role in advancing the state-of-the-art in helicopter rotor systems design.

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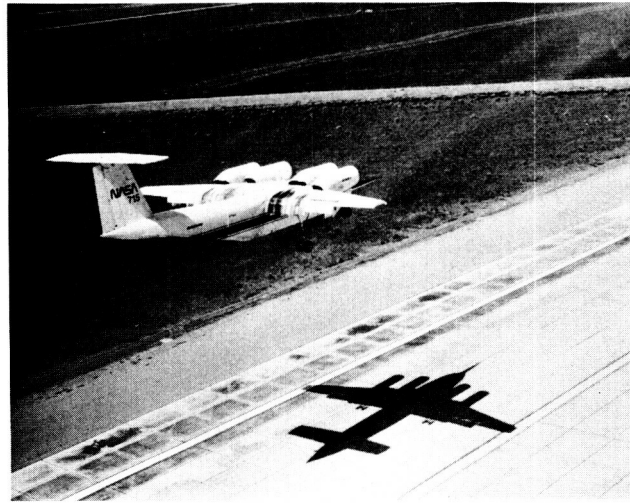
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Fig. 1 The Quiet Short-Haul Research Aircraft (QSRA).

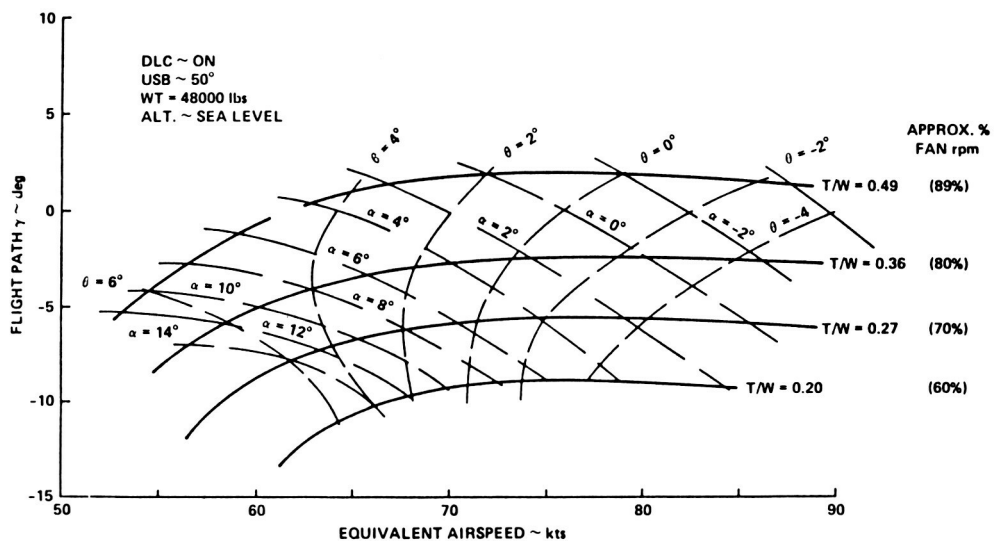


Fig. 2 Flightpath vs. velocity diagram: landing configuration.



Fig. 3 QSRA on approach to USS Kitty Hawk (CVA-63).

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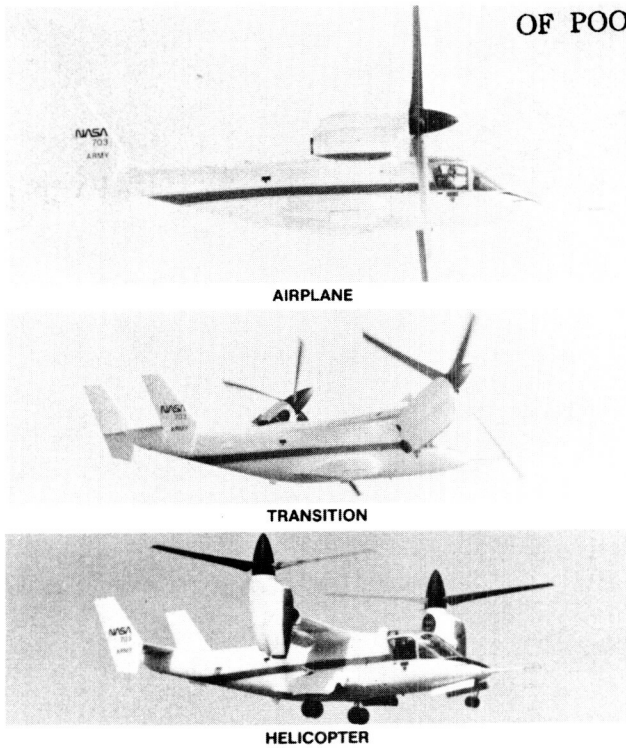


Fig. 4 XV-15 Tilt Rotor Aircraft.



Fig. 5 XV-3 Convertiplane.



Fig. 6 RSRA Helicopter Configuration.

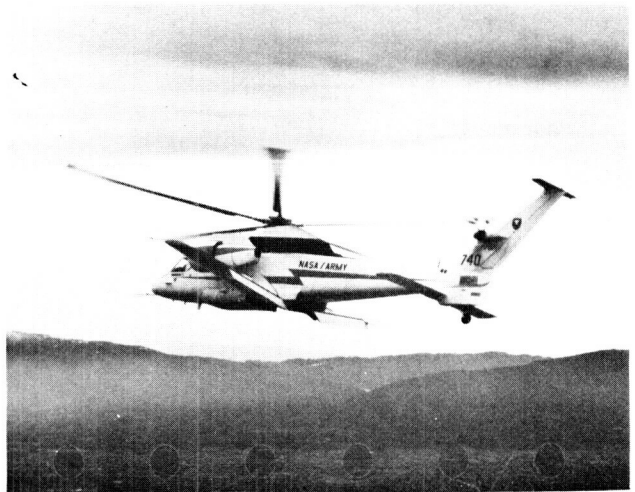


Fig. 7 RSRA Compound Configuration.

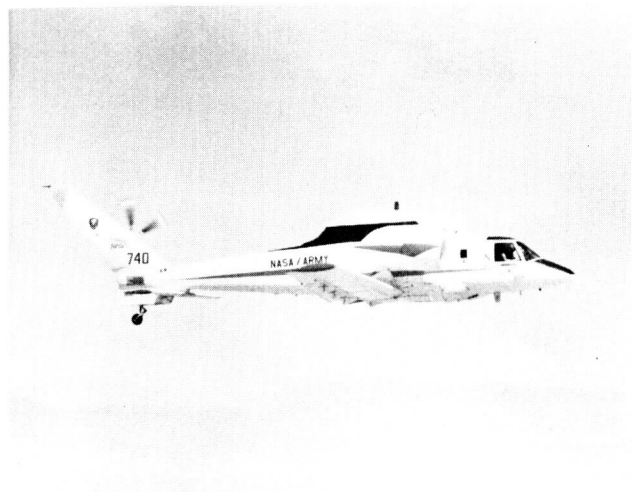


Fig. 8 RSRA Fixed Wing Configuration.



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16. Abstract In 1976 NASA elected to assign responsibility for each of the various flight regimes to individual Research Centers. NASA Ames Research Center at Moffett Field, California was designated lead center for vertical and short takeoff and landing, V/STOL research. This paper will discuss from the test pilot's perspective the three most recent flight research airplanes being flown at the Center: the Quiet Short Haul Research Aircraft; the XV-15 Tilt Rotor Research Aircraft; and the Rotor Systems Research Aircraft.					
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